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CONTENTS

| | PAGE |
|---|---|
| Granulated Lime and Manures ... ... | 81 |
| Some New Aspects of Soil Acidity ... ... | 84 |
| The Utilisation of Clonal Cacao ... ... | 86 |
| Evaluation of Some Clones of *Derris elliptica* ... ... ... ... | 89 |
| Studies of Diurnal Variation in the Body Temperature of the Tropical Threequarter bred (Holstein-Zebu) Dairy Calf ... ... | 94 |
| Chemical Notes ... ... ... ... | 100 |

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## GRANULATED LIME AND MANURES

In this issue of "Tropical Agriculture", some abstracts from a thought-provoking article concerning certain liming experiments recently carried out in Missouri are presented and briefly discussed. The experiments show that, under certain circumstances, it may be best to apply pulverised limestone in rather coarse form instead of finely-divided as is usually advised. The reason for this is that, in many infertile acid soils, it is not soil acidity that is the limiting factor for crop growth but lack of soil calcium, a nutrient element which plant-roots may procure just as easily from relatively large grains of limestone by means of their enveloping root-hairs as from tiny particles such as comprise the standard 100-mesh material customarily employed for liming acid soils.

It seems likely from laboratory analyses that many acid soils occurring, for instance, in sugar-cane fields and peasants' holdings in the British West Indies, are markedly deficient in nutrient calcium and might therefore respond in similar manner to relatively small dressings of coarse limestone. Some of our West Indian acid soils show lime requirements (as determined by conventional laboratory methods) of magnitude up to 20 or 30 tons to the acre of calcium carbonate needed to render them neutral. Such large dressings are so expensive and cumbersome to spread that, in practice, the planter or peasant usually prefers to leave the land unlimed. Perhaps in future he may be induced to try much smaller dressings of a coarser and therefore cheaper grade of limestone such as 10-mesh crushed rock. Indeed, it may be sufficient to incorporate a small quantity of coarse limestone in the soil at each spot or "hole" where a plant is to be grown; instead of broadcasting a much larger amount in an attempt to effect complete neutralisation. For example, in the case of a sugar-cane field having theoretical lime requirement of, say, 20 tons per acre-foot, and carrying about 2,500 stools to the acre (4 x 4 feet planting), it might suffice to place one or two pounds weight of 10-mesh limestone in each hole and to mix it in or cover it lightly with soil before planting the setts, or to sprinkle it along the furrows if long stalks are used as planting material. With his method and at this rate of application, namely, about 1 to 2 tons of coarse limestone per acre, not only will a great saving in costs be effected, but in many cases, a vast improvement in yield might be obtained. The

idea in any case is well worth testing, and it should particularly commend itself to small owners who are attempting to grow provisions (including maize and other grain crops) in highly acid soil.

It is ovbious that, if lack of fertility in a given soil is caused by an inadequate supply or a too-slow rate of formation of available calcium, complete neutralisation of its natural acidity, such as might be achieved by thorough liming, would ultimately defeat its own object, for it would produce a large supply of soluble calcium salts which would be liable to rapid and entire removal by heavy leaching in a wet climate, leaving a soil in which calcium might be much less readily available to plants. This illustrates a general principle of soil fertility which stresses the fact that the continuous natural process whereby nutrient-rich minerals are broken down by weathering through the action of water is greatly enhanced or accelerated by the presence of acids. The chief acid that operates in rock weathering is carbonic acid derived from the air and by the oxidation of rotting vegetation and soil organic matter and by the respiration of roots of living plants and soil micro-organisms. Its effects are augmented by those of nitric acid produced in traces in the atmosphere during thunderstorms and brought down by rain showers. If a condition of alkalinity is artificially established in the surface soil by thorough liming, then these natural soils' acids are neutralised and fixed in the surface layer; they cannot therefore penetrate into the substratum where they would normally bring about the progressive liberation of mineral nutrients such as potash. Most undisturbed soils are distinctly acid in reaction, even those that are developed over calcareous rocks. It is only when calcareous rock soils are extensively eroded or when they are deeply ploughed so that the parent material is brought to the surface that undesirable alkalinity prevails in the upper rooting zone.

Other effects of lime-induced alkalinity may be even more far-reaching, in that it causes the suppression of essential nutrient elements such as iron and manganese, and of important trace elements, such as copper, zinc and cobalt which they precipitate as insoluble and therefore unavailable compounds. They also include the immobilisation of phosphorus which will be considered in greater detail later. It is evident that, could thorough liming be carried out to completion in the field as it can be in the laboratory by the intimate mixing of an excess of finely-divided lime with an aqueous suspension of the soil, then the undesirable results that would follow might completely outweigh any benefits that the process could confer.

Students of soil science are generally puzzled by the demonstrable fact that, in most highly-fertile soils, the greater part of the total exchangeable base capacity is taken up by calcium, leaving only a small part (usually less than 10 per cent.) to accommodate all the other important exchangeable bases, namely, potassium, sodium, magnesium, manganese, iron, aluminium and certain exchangeable trace elements. In particular, such calcium-saturated soils would appear to be deficient in available potassium, although the evidence of vigorous crop growth refutes this expectation. Quite likely, nutrient elements derived directly from weathering soil minerals continually augment or replenish the supply of exchangeable potassium, as well as of magnesium, manganese and other elements occurring in exchangeable form as colloidally-adsorbed or surface-combined entities. They may also largely contribute to plant nutrition directly.

Soil parent materials often contain potash-rich clay minerals such as illite (hydrous mica) which seem to be particularly abundant in sedimentary rocks of widespread occurrence in the British West Indies. Numerous tests carried out at the College, both in the laboratory and in the greenhouse, have repeatedly shown that soils derived from such materials usually contain sufficiently large supplies of easily-available potash to satisfy the needs of most tropical crop-plants. The only way in which these natural clay minerals can be induced to yield up their store of potassium is through hydrolysis by soil acids in solution. This process, as we have seen, is inhibited when conditions are rendered completely alkaline, but it may be accelerated and intensified by increasing the rate of production of carbonic acid by continuous vigorous cropping and by the application of bulky organic manures, composts and mulches.

This brings us to the most important case of all, namely, soil phosphates. It is well known that there are several sources of phosphorus in soils, chief among which are organic phosphorus compounds* (such as nucleic acid) derived from dead plant residues and abundant in soil organic matter and humus, as well as various mineral forms containing tri-calcium phosphate, and also phosphates of iron and aluminium. These show widely-differing degrees of solubility in soil water (the "soil solution") and in various extracting agents used in the laboratory. Thus organic phosphorus compounds yield up little or no phosphate to the soil solution nor to dilute acid extractors unless and until they are completely decomposed. Their phosphorus contents then finally appear as ordinary tri-calcium phosphate which is by far the most soluble and therefore the most readily available of all the phosphorus compounds occurring in soils and the only one which comes into solution when acid reagents are applied in laboratory soil analysis.

The most insoluble of all soil phosphorus compounds, however, are undoubtedly iron and aluminium phosphates. These generally occur in highly acid calcium-deficient soils, which, even though they contain a fair total amount of phosphate, may yield up so little available phosphate to the soil solution that the limiting factor for plant growth in these soils may be an acute shortage of easily-available nutrient phosphate.

The marked fixation of phosphate† by highly acid calcium deficient soils which occurs when they

* *Trop. Agriculture*, Trin., 1944,, XXI, pp. 230-231.

† *Ibid.*, 1942, XIX, pp. 37-38 and *Ibid.*, 1943, XX, pp. 223-224.

are treated with soluble phosphatic manures is too well known to warrant detailed discussion. The amount of added phosphate which may thus be fixed may reach very high proportions of the order of 1,000 lb. $P_2O_5$ per acre, or about 2½ tons of superphosphate manure. This amount is so large that it would rule out any hope of satisfying the phosphate requirement of such a soil economically by the direct use of soluble phosphatic manure. Other procedures fortunately are available for successfully manuring such soils, for example, heavy liming in the ordinary way, the use of silicate instead of phosphate for satisfying most of the phosphate requirement, and even the application of molasses whose decomposition in the soil renders the phosphate soluble. These three methods are also likely to be expensive as well as not entirely satisfactory in every case.

The most effective way of treating highly acid phosphate fixing soils (which, by the way, mostly comprise red or yellow highly ferruginous mature soil-types* customarily termed Tropical Podsols and Tropical Lateritic Soils) is by the so-called "placement" method. This method has already been described in this journal.† It consists in the application of a limited quantity of phosphatic manure in bands or strips, either alongside the row or drill where the crop is to be planted or the seed to be sown, or at the bottom of the deep furrow which afterwards may be partly filled with soil before planting. The chief danger, of course, is "burning" the young crop, caused by contact with a concentrated solution of the (soluble) manure. This is likely to occur in dry soils in dry weather. The danger may be reduced by careful adjustment of placement distance. Both soluble and insoluble phosphatic manures may severally be applied by the placement method; which kind may prove to be the most effective and economical can only be decided by field trial. The powder form of manure is probably the easiest to apply, but, in view of what has been written above regarding the use of coarse limestone in preference to finely-divided lime, the best form is doubtless some granular or granulated product which nowadays can be manufactured even from powdered soluble phosphates such as superphosphate. In the case of ground rock phosphate, basic slag or ground bone phosphate, a suitable relatively coarse-grained material may be selected if the granulated powder form is not obtainable.

Coarsely-granulated manures in the form of pellets or small briquettes have also been applied by the placement method. These may be compounded of more than one manure, for example, certain kinds of briquettes used in Hawaii‡ consisted of Portland cement or plaster of Paris or powdered basalt-rock as filler and binder, mixed with bone-meal, rock phosphate, blood-meal and potassium chloride, and mechanically compressed so as to impart physical stability. During use, plant-roots grow closely around and within the briquettes which slowly disintegrate without becoming mixed with the soil. In this way, phosphate fixation and potash leaching are prevented.

Another method of placement manuring is the crowbar or hole method,* applicable to tree-crops and garden plants. This consists in making a series of holes around the tree with a crowbar or auger and putting into them small amounts of a mixture of manurial and corrective substances, such as soluble phosphates, ferrous sulphate, salts of manganese, copper and zinc, and sometimes sulphur and cotton-seed meal which helps in the dissolution and diffusion of the other components.

Placement methods are particularly useful where both lime and soluble phosphate are to be applied together, or where soluble phosphatic manure is to be applied to an eroded soil developed over marl or some other calcareous rock, or to soil which has been ploughed too deeply so that its calcareous parent material is brought to the surface so as to become mixed within the upper layer. In each of these three cases there is danger of undesirable phosphate fixation of another sort than that already considered, namely, fixation as so-called "carbonato-phosphate". This coumpond is said to be just as insoluble and its phosphate just as unavailable as phosphate of iron or aluminium. The danger cannot be avoided if lime and soluble phosphatic manure are both applied in finely-divided form, but it can easily be circumvented by using coarsely-pulverised materials or granulated powders, provided the granules or aggregates are sufficiently stable so as not to disintegrate too rapidly when drilled into the land and exposed to soil moisture.

Examples of calcareous soils which might benefit greatly by this method of phosphate manuring are widespread in the British West Indies, for instance, eroded Rendzina occurring in Trinidad† and Antigua‡ whose peculiar phosphate requirements have been examined at the College, both by laboratory and greenhouse methods.

There seems to be no doubt whatever that this newer view of liming and manuring soils, particularly with phosphatic manures, is more rational than the older generally-accepted view, especially since it offers a solution of certain practical soil problems which hitherto have proved difficult to solve. It would also appear to suggest means of improving certain highly acid deteriorated soils such as phosphate-fixing red ferruginous soils and deeply eroded marl soils which so far have defied all attempts at amelioration, at least by simple and inexpensive methods.

The world's most fertile soils are unquestionably the highly aggregated markedly heterogeneous immature Azonal soils, whereas the least fertile and agriculturally unsatisfactory soils are developed over mature end-products of profound rock decay in which all the mutable minerals have been completely broken down and their nutrient products removed by continued leaching under wet climates, leaving a homogeneous mass of inert

* *Trop. Agriculture*, Trin., 1941, XVIII, pp. 238-243.
† *Ibid.*, 1945, XXII, pp. 197-199.
‡ *Ibid.*, Trin., 1934, XI, p. 219.

* *Trop. Agriculture*, 1941, XVIII, p. 208.
† *Ibid.*, Trin., 1941, XVIII, pp. 214-221.
‡ *Ibid.*, 1938, pp. XVI, pp. 183-186.

materials comprising in the extreme case a mixture of crystalline quartz and unctuous kaolinic clay stained uniformly red by haematitic iron oxide. Senile soil-types such as this normally are clothed with primeval forest which survives solely through a circulation of nutrients occurring in a sharply-demarcated surface litter composed of residues from former generations of plants. When the forest is felled and this highly organic layer is removed by erosion or decay, the remaining earthy material is usually highly acid and very deficient in available phosphate. It is material such as this which is frequently offered to the agriculturist as a medium in which to grow his crops in many parts of the wet tropics where forest destruction and soil erosion have all too conspicuously played their parts. Small wonder, that the practical and economical methods required to render them productive are somewhat drastic and unconventional and likely to differ essentially from those customarily practised by the arable land farmer in temperate regions.

F.H.

## SOME NEW ASPECTS OF SOIL ACIDITY

**Some new aspects of soil acidity based on experiments on the relative effectiveness of coarse and fine pulverised limestone**

In an article which appeared in *Soil Science* for March, 1946 (Vol. 61, No. 3, pp. 265-271), Dr. W. A. Albrecht of the Missouri Agricultural Experiment Station, Columbia, Missouri, United States of America, presents evidence to prove that the application to an acid clay soil of relatively coarsely-ground limestone produces greater yields of corn (maize) than when finely ground limestone is used at the same rate. This result at first sight would appear to be anomalous, but the magnitude of the differences in yield, in favour of the coarser material, leaves no doubt that the effect was highly significant.

The total yields of corn for eight successive crops were indeed higher with 300 lb. per. acre of 10-mesh limestone than with 600 lb. per acre of 100-mesh limestone, and also considerably higher than for equivalent amounts of calcium in the form of gypsum on calcium chloride. For the 8-year crop average, the difference in yield was 4 bushels of corn per year in favour of the coarsely-ground limestone.

In attempting to explain this result, the author stresses the fact that notable increases in yield are given in these experiments by relatively small dressings of calcium-containing substances, which implies that it is *nutrient calcium* that is acting as the limiting growth factor. He considers that "when an application as small as "300 lb. per acre of 10-mesh limestone is as "beneficial as is indicated by these results, its "effects can scarcely be ascribed to the reduction "of soil acidity", and that "the effects of such "a small application must put the limestone "into the category of a plant nutrient or "fertilizer".

The soil examined was Putnam Silt-Loam, having pH 5.5. Without lime treatment this soil was quite incapable of supporting the growth of a cover crop of Sweet Clover, but, with the best limestone treatment, it gave more than 50 bushels of corn to the acre, which is a good average yield.

The author in attempting to explain the results obtained in these interesting experiments offers the suggestion that "a few foci of less-soluble "limestone in the soil volume reacting slowly with "the clay are more effective in providing the "plant with calcium than are the more soluble "forms reacting rapidly with the clay", and invokes a mechanism "in which there are, first, "a movement of nutrients from the mineral "and rock fragments to the acid clay by an ex-"change for the hydrogen, and, second, further "movement of these nutrients from the clay to "the plant-root". According to this concept, "the "limestone seems to nourish the plant with calcium "more effectively when granules or particles of silt "and sand size are distributed through the acid "soil as mineral sources than when the calcium "supply is only that absorbed on the clay."

These suggestions are fully in accord with modern views which favour the use of *granular* fertilizers rather than finely-divided substances such as have been found not to give good results with some soils greatly deficient in particular nutrients, even when applied in relatively large dressings.

Complete neutralisation of the acidity of a soil is now known to lead to nutritional troubles, for example, it immobilises iron and greatly lowers the availability of phosphorus, as well as renders insoluble the sparse sources of trace elements such as manganese. Indeed, soil acidity is nowadays regarded as one of the essential conditions by which plant nutrients are weathered out of the reserve minerals and passed on to and fixed by the particles of soil colloids from which the growing and advancing plant root may readily obtain its supply of nutrients.

In the light of these considerations, it becomes evident that a different view of plant nourishment by different kinds of soils must be taken than that which is commonly accepted and in this connection a final quotation from Dr. Albrecht's stimulating article will commend itself to students of crop ecology.

He writes :—

"The significance of soil acidity as a nutrient mobilizer in ecology may be realized when it is recalled that most vegetation is naturally placed on acid soils and that little is on neutral and alkaline soils. Acidity in the soil is one of the necessary conditions by which nutrients are weathered out of the reserve minerals, passed to

and stored on the colloidal clay, and held there in exchangeable forms from which the advancing root can rapidly take its needed supply during its short growing season. This concept of the mobilization of the plant's nourishment from mineral nutrient reserves in rock fragments simplifies the ecological array of different plants in relation to soil development. On the soils under low rainfall and scant soil development, (which are mainly rocks and rock fragments with little clay saturated with cations other than hydrogen), the annual quantity of vegetative production is low. Woody shrubs or trees occur on such soils".

"Soils with the original rock reserves broken down to sand and silt sizes, but not highly leached, have larger amounts of clay. This is not so highly saturated with basic cations but that, through plant growth, much hydrogen is active in weathering the mineral reserves and passing their nutrients to the growing crops. Here are the conditions that invite the prairie grasses. These grasses survive under the moderate rainfalls and find in the soil the essential fertility coming from mineral breakdown that constructs the vegetation of compounds more nourishing as feed than is the wood or even leaves of forest trees."

"But when higher rainfall and temperature develop the soil until it is largely clay, with a few coarse mineral particles that are mainly quartz, these mineral fragments are of no significant value as nutrient reserves to be weathered by the acid clay. Consequently, the natural crop on such highly developed soils is forest. Forest trees nourish themselves by gathering fertility at a slow rate from rock breakdown as their roots penetrate more deeply. But they probably nourish themselves much more by rotating their fertility from the annual dropping of leaves to the soil, whence they return it again into tree growth. Highly developed soils hold little fertility on their hydrogen-saturated clay, and are delivering at a very slow rate small amounts from the mineral nutrient reserves held in the small portion of the silt fraction that is other than quartz."

"This ecological pattern suggests that the prairie soils are fertile and productive because their sands and silts are unweathered rock fragments other than quartz. These sands and silts represent reserves of fertility to be weathered or broken down for nutrient release. Such soils are productive because on their significant amounts of a moderately acid clay are stored fertility reserves in available and exchangeable forms, while more is being mobilized from the fertility reserves. This mobilization is the result of root action and microbial activity, with their resulting acidity or hydrogen going to the clay as the agency weathering the nutrient mineral reserves. It is in these mineral nutrient reserves, then, of the fragments of other-than-clay minerals, that the basic potential fertility of our soil, lies."

"When the use of limestone on our soils is considered in terms of crop behaviour rather than in terms of the degree of soil acidity, the oil need not be considered as a medium of infinite uniformity approaching molecular dimensions. It need not be considered as containing all the necessary plant nutrients within every small unit of soil volume, when the application of a fertilizer in the bottom of alternate plow furrows is about as effective as when application is made in every furrow, nor when it is suggested that the highly buffered activity of calcium absorbed on the clay has much greater activity in the calcium-saturated interfacial areas between a limestone particle and the surrounding clay. It would not seem a stretch of the imagination to believe that plant roots might search out the more widely separated foci of different mineral fragments around which the clay is saturated by their particular nutrient offerings. One need not believe the plant unable to grow unless all the clay is uniformly of a specific degree of acidity. It seems more reasonable to believe that the plant is growing much better if its advancing roots find one area around a limestone particle that may be nearly neutral but providing much calcium, then at some distance another area, more acid, where iron can be taken, then another acid area where around some feldspar grain its potassium is slowly made available, then another where the acidity is moblizing the phosphorus, and still others where manganese and the different essential nutrient elements are on the clay in exchangeable form because the clay is in contact with some mineral fragment and maintains itself in a weathering equilibrium with it. If this is the proper concept of the soil-plant relationships then it is easier to understand how the coarser or granular particles of limestone can be more effective in growing Sweet Clover as green manure for the corn crop than is 100-mesh limestone or even the sulphate and the very soluble chloride of the calcium taken up readily and held in exchangeable form on the clay."

*Summary*: The facts presented by Dr. Albrecht support the concept that the soil need not be a uniform medium as regards degree of acidity or the distribution of all of the essential plant nutrients. Rather the soil may be a mixture representing a heterogeneous collection of foci of each of these in the mineral or rock forms, weathering slowly while in contact with the acid clay. Plant growth may then represent the summation of root contacts with all these different centres of fertility as the roots move to and get from them all that is needed for maximum crop productivity. According to this concept, both the very soluble and the less soluble nutrient materials applied in granular form would maintain this seemingly beneficial heterogeneity of fertility sources for better plant growth than would any practice aiming to blend the soil to the uniformity with which nutrient solutions are endowed. This concept points to possible trouble in saturating the clay with calcium only, which would displace other essential elements. It suggests also an economy in limestone use when this ameliorant will serve without the extra cost of its finer grinding.

# THE UTILISATION AND FUTURE OF CLONAL CACAO

BY

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The success of the best ICS clones at River Estate (*vide* "Results of Cacao Experiments in 1944-45". *Trop. Agric. Trin.* **23**: 63-65, 1946) provokes thought about both the present and the future of selection and vegetative propagation among the Trinitario cacaos.

On the one hand the information and the planting material available in 1946 represent only a modest start in cacao improvement, and are likely to be surpassed in a few years. On the other hand, the results of the last fifteen years of research are too important to be ignored. There can no longer be any doubt that, if the production of "fine" cacaos is to be kept up at all, the clonal propagation of selected trees must within the next decade or so become standard practice in this section of the cacao industry, with much the same revolutionary effect as it has already had in the rubber industry.

The subject for enquiry, then, is how planting policy can be framed in order to turn available knowledge to the greatest advantage, whilst leaving the planter free to benefit from each subsequent advance in knowledge or improvement in planting material. The object of this discussion is to show that both results can be achieved, provided that the policy adopted is a long-term one.

The necessity for a long-term policy arises from circumstances common to all tree crops. On the research side, with any system of selection or breeding, there must always be a lag of at least ten years between the initial recognition of a promising type and the mass production of tested planting material. On the commercial side, the proportion of an established estate that can be converted to new material in any one year is usually limited rather narrowly by economic factors. Both considerations indicate the advantages of having both research and renewal policy planned on the assumption that they are permanent necessities, to be continued as far into the future as anyone can foresee. On such a basis they can be fitted together ideally.

Let us suppose for the sake of argument that a planter decides to replant 4 per cent. of his acreage annually. A replanted field, even with selected cuttings, is virtually out of production for four years, and to be well on the safe side we may reckon five. At the end of five years, therefore, 20 per cent. of the estate is out of production. Thereafter the fraction remains constant, and, as the 80 per cent. in bearing comes to be more and more composed of the better trees, total production soon overtakes its original level and rises far above it. The renewal is completed in 25 years but—and this is an important point—if research has been continued along right lines there should long before that time be planting material available better than that with which the programme started. Thus the clones used for replanting will change every few years as better ones come in, and at the end of the 25 years it will probably pay the owner to begin the replacement of the oldest clonal material, though not necessarily on the same annual percentage. The actual percentage to be renewed annually thereafter must ultimately depend on the economic life of the clonal trees, which has to be discovered, but whether it be as low as 2½ per cent. or as high as 5 per cent. (the probable limits) the principle of continuous replanting remains the same. By this means the capital value of the estate is maintained and even continually enhanced, instead of being allowed to deteriorate by the gradual passing of the fields into an uneconomic old age.

On the research side, a continuous supply of improved material may be expected from several sources. In the first place, it may be obtained by further selection from the existing seedling cacao population of Trinidad and Tobago. At present, the only clonal material immediately available consists of some half-dozen ICS clones that have been sufficiently tested to be recommended. There will probably be several more added to the list during the next few years as further tests proceed, but there will never be as many of these as we should think desirable for the full exploitation of selection.

It must be pointed out that the primary aims of the Cacao Research Scheme at I.C.T.A. are useful knowledge and improved methods. Good planting material is a secondary product; and the exploitation of such material together with the application of new methods, must rest largely with the industry itself. To quote from the Third Annual Report on Cacao Research, 1933 (p.24): "Our aim is less to find the most efficient trees in all Trinidad, which would be an academic ideal, than to establish standards of efficiency represented by the best we can find in a necessarily limited search". The present standards of efficiency are the best half-dozen ICS clones; and considering that they were selected from a fairly large sample, they may approach in performance the best in the whole population. But there are doubtless still in the Colony dozens of trees from which clones of equal merit could be propagated, and among them at least a few superior, either in actual yielding power or in ancillary characters that are ultimately just as important. It is highly desirable that more of these should be found, and the only way in which that can be done is by the co-operation of every cacao planter in the Colony. The high standard of performance of modern varieties of most fruits and vegetables is still due less to the labours of a few geneticists and professional plant breeders than to the personal interest of millions of gardeners who for generations have watched and known their plants and selected superior individuals for propagation. In these days the scientist can

help to speed the process of improvement, but he can never replace the services that can be rendered by a host of interested non-professional observers. Apart from any other consideration, there are not enough scientific officers available to cover all the research needed, and the few we have should obviously be concentrated on the jobs that the planter cannot do for himself.

It is suggested that every cacao planter should be on the look-out for trees of outstanding performance in his seedling fields as long as seedling fields remain in cultivation—and obviously there must be some for many years to come. Having selected the few that he likes best, he should bring them to the notice of the Department of Agriculture, whose technical officers will be able to judge whether these trees are sufficiently promising to justify preliminary trials. The next step should be to bud from each, "provisionally approved" tree a small progeny of a dozen or twenty plants and grow them in a plot convenient for further observation. This may be carried out either by the Department or on the estate. By the time the buddings are five years old there should be no doubt which of them are promising, and the best will be worth the expense of propagation by cuttings and strict statistical comparison with existing standard clones. This last and most expensive stage should be carried out by the Department of Agriculture on its central experiment station, where provision might be made for planting about 25 new clones each year, in the hope that perhaps two or three of them would prove really valuable. The whole process may appear to be tedious and slow, but it is the most economical means of attaining the desired end.

A second possible source of improved planting material is by introduction from outside the Colony, through the research organizations. In general this may not be very important, since we already have such a wealth of forms in Trinidad. But an extremely important special example is provided by the material introduced by the Trinidad Department of Agriculture, from the Amazon basin and elsewhere, for its immunity or high resistance to Witches' Broom disease. Presumably, when they have been adequately tested, clones of this Amazon cacao will take their place on the list of available and recommended material.

The third source of better clones is to be looked for in planned cacao breeding. Improvement cannot be continued indefinitely by simply hunting through the existing seedling population, though there is much to be done before that method is exhausted. Cacao breeding, in the sense of planned crossing of good clones to enhance their favourable characters, and deliberate building-in of such desirable characters as resistance to pests and diseases, has yet to begin. It involves fundamental research, and the Cacao Research Scheme hopes to make a start almost immediately. Thus by the time the testing of the existing ICS clones is finished, there should be available the first of a new series selected from new hybrid populations.

In short, from one source or another—the original ICS series, introductions by the Department of Agriculture, planters' selections, and new hybrids from the Cacao Research Scheme there should always be enough promising material to keep a clone-testing system continuously operating and turning out varieties each a little better than the last. There is nothing new in that concept, except its application to cacao, for it already represents the state of affairs in the sugar industry and (subject to recent interruptions) in plantation rubber. It is important to remember the inevitable lag between research and application. If a few selections are made every year, there should be (after the initial lag has been overcome) a steady supply of new clones every year, or at least one or two really superior varieties in every decade. But any slackening or failure in the basic research will be reflected in an absence of improved material ten to fifteen years later and a temporary arrest of progress at the latter date.

It seems quite likely that in the more distant future the industry will return from clones to seedlings, using seedling material raised by entirely new methods and entirely different in constitution from the present mixture. Seedling progenies raised from crosses between clones will at first be used chiefly for the selection of new clones better than the original ones, but when breeding has proceeded for several generations the progenies from controlled crosses may be expected to give yields comparable with those from the best clones. Whenever that stage is reached, there are strong genetical arguments for preferring seedling to vegetative propagation in the commercial fields, but they need not be elaborated here. The necessary conditions are unlikely to be reached in much less than fifty years from now, and the possibility is thus of mainly theoretical interest to the present generation of planters. It affects neither the proposition that clones will be the most profitable material to plant for the next 25 to 50 years, nor the soundness of a planned system of continuous replacement of trees in the crop fields. It does, however, concern the cacao breeder, upon whom there is a moral obligation to ensure as far as possible that in selecting the best material for immediate use he does not reduce too much the useful natural variation in the cacao tree population as a whole.

The outlook for the future has been discussed at some length, because it helps to illuminate the present position and to put into perspective the very small start that has been made in cacao improvement. There are, however, some more immediate questions, which may be discussed here although they cannot all be completely answered.

In the first place, the planter naturally seeks advice in his choice of clones; but all the research officer can do for him is to give him the results of experimental plantings. We believe that results obtained at River Estate, on a mediocre soil, without any manuring since 1942, and in spite of some losses from Witches' Broom disease, should be reliable in the sense that the clones performing

best under those conditions are not likely to fail on any reasonably good soil in the Colony. It is, however, quite possible for their order of merit to change on other soils and in other districts, and in this respect at the present stage it is absolutely necessary for the planter to be his own experimenter. He can have confidence (as fully as confidence can ever be felt in agriculture) that any clone distributed by the Department of Agriculture will be considerably better than ordinary seedling cacao. Which clones will give the highest yields on his own particular estate, he must find out for himself.

The most satisfactory all-round clone at the time of writing is certainly ICS 1, whether judged on yield alone or on other points in its behaviour, such as ease of establishment and general habit. In actual yield ICS 8, 16, 45, 60, 95 and 98 are so close to it (60 yielding slightly more and the others slightly less) that they can all be recommended on that character. ICS 16 and 60 are self-incompatible, but that need be no practical drawback unless they are planted in large blocks by themselves. Planters wishing to grow only large beans will avoid ICS 95 and 98, and those particularly interested in Criollo and near-Criollo types will be well advised to try ICS 45 and 60. ICS 6 is a good self-compatible clone not much below the others listed, and in some places might do equally well. That is the gist of the information available.

The next question is whether the various clones should be planted by themselves or mixed. Self-incompatibles should ovbiously, if planted at all, be mixed with enough self-compatibles to ensure adequate fertilization. That is easily done, and it does not at present appear desirable to reject entirely a number of extremely promising clones simply because they are self-incompatible. Our opinions on this point may change when we have more first-class self-compatibles to choose from, but there is no present reason to suppose that any harm can result from the planting of self-incompatible clones as long as they are not in solid blocks and do not constitute more than 50 per cent. of the field. With self-compatible clones there are several considerations to be balanced in coming to a decision. In favour of the planting of whole fields with single self-compatible clones there are all the arguments in favour of uniformity in product, and especially the advantage of even fermentation. In favour of planting mixtures, the chief argument is that this is a form of insurance against unforeseen weaknesses in any one clone; probably it also tends to minimize fluctuations in yield from season to season, and to spread the crop over a longer period in each season.

Thus there are some advantages either way, and whether several self-compatible clones are mixed in the same field or grown in separate fields may not on balance matter very much. What would seem highly undesirable at the present stage is that any planter should confine all his plantings to one clone. There are three good reasons why he should not do so. The first is expressed in the old proverb against putting all one's eggs into one basket. If the whole of Trinidad were planted with ICS 1 and a new disease were then to appear, to which ICS 1 proved specially susceptible, the results might well be disastrous. That contingency is unlikely, but similar things have happened before now in agricultural history.

The second reason for using a number of clones is that at the moment we almost know nothing about quality in cacao, and it may be that the distinctive quality of Trinidad cacao depends in part upon its being a mixture. Undoubtedly the seedling mixture has certain undesirable qualities, irregular size and shape of beans for example, which can be modified by the use of clonal material; but in the subtler components of quality, which we do not yet understand, it is quite possible that no single clone can give exactly the flavour that the manufacturer expects from Trinidad cacao. With fuller knowledge we may find it necessary to substitute for the uncontrolled mixture of seedling cacao a controlled mixture of certain clones. Meanwhile it would appear unsafe to allow any one type to predominate too strongly in the product, until we are quite sure that it is a satisfactory type from the buyers' point of view.

The third reason for diversification is implied in the first two. Planters and research officers alike need above all things more information about the behaviour of clones before they can achieve the most profitable fitting of type to environment, and this information can only be obtained quickly by actual plantings in as many places as possible. It must be emphasized again, even at the risk of tedium, that cacao research has reached a stage where it simply must not be left entirely to a handful of specialists, for whom the job in all its ramifications is too big. "Every planter an experimenter" is the only principle which will ensure progress.

It may be noted that, when clones are mixed in the field, some care is desirable in making the mixture. One planter has already pointed out, for example, that a mixture of such extreme types, as ICS 45 and 98 (or even 45 and 1) would be likely to ferment badly, because the components need different treatment for the best results. Here, again, more information is needed, and for the present it may be advisable to keep 45 and 60 separate from other clones. There appears no strong reason why 1, 6, 8, 16, should not be grown together; 95 and 98 possibly require slightly longer fermentation than the others.

In conclusion, lest any false impression be given by the emphasis in this article on doubts, lack of knowledge and the need for experimentation, let it be stated clearly that the difficulties mentioned apply with greater force to the existing seedling cacao. To get the best possible results from clonal cacao will need much further research; but to get good results from it is open to anybody. We shall all make some mistakes with it in the next few years, but there is no reason to fear that they will be disastrous mistakes; on the contrary, there is every reason to believe that in spite of them the gradual change over from seedling cacao will prove highly profitable.

# EVALUATION OF SOME CLONES OF DERRIS ELLIPTICA

BY

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## Introduction

IT is recognized that the presence of rotenone is an inherent characteristic of some plants; as a plant constituent it is known to occur only in the family Fabaceae and in only a few species of this family. The concentration of rotenone in those plants in which it does occur varies to such an extent that only certain species can be used in the production of the powerful insecticide based on the presence of rotenone and allied compounds. Furthermore, it has been shown that within species certain varieties are superior (1). Within varieties it has often been assumed that superior clones could be selected. In this paper data are given concerning the selection of clones within the variety Changi No. 3 of *Derris elliptica* (Wall.) Benth.

The fact that rotenone deposition is greatly affected by climate and soil conditions makes it imperative that a group of clones be tested in a statistically rigorous manner lest differences due to external conditions be misinterpreted as due to inherent characteristics. This group of clones was tested twice, the data being analyzed each time to establish the significance of differences. The correlation coefficient between the two rankings was calculated to determine whether the orders obtained were in substantial agreement. In this manner it was demonstrated that rotenone content is a clonal characteristic. However, it is possible that the order of rank obtained in this type of experiment might be altered if the external conditions were changed. This is true with varieties of many plants and for that reason they should be tested under the conditions under which they are to be grown on a large scale.

There are numerous criteria upon which ranking of *Derris* selections could be based. Clearly, the real value of the clone depends upon its yield of insecticide; that is, the best clone is that which gives the maximum insect control per plant, per acre, or per unit of effort expended to produce the root. Generally, the amount of insect control is different from that which would be expected on the basis of rotenone content alone because of the presence in the root of variable amounts of insecticidal compounds other than rotenone (2). However, since the measurement of true insecticidal value is a difficult task, the simpler alternative of ranking on the basis of the principal toxic compound, rotenone, is more attractive. With a crop such as *Derris*, there are also several other desirable characteristics which could be considered; *i.e.* the number of cuttings produced, value as a cover crop, value as a legume in nitrogen fixation in the soil, and resistance to pests and adverse weather conditions. However, to maintain proper emphasis, these criteria were not regarded as critical because differences among clones in these respects would be expected to be small. The criteria selected here were yield of roots, rotenone content of the roots, and yield of rotenone. (The root yield multiplied by the rotenone percentage gives the rotenone yield). The latter criterion is important because at present *Derris* root is purchased strictly on the basis of rotenone content just as though the buyer were purchasing rotenone without regard for the accompanying plant tissue.

## Evaluation Trials

### FIRST EVALUATION

This evaluation study was made with 9 high-rotenone clones of the Changi No. 3 variety of *Derris elliptica*. The design of the experiment was such that the magnitude and range of rotenone percentages were sufficient to enable a tentative ranking of the clones.

According to Bangham (3) the Changi No. 3 plants from which these high-rotenone clones were originally chosen were obtained from Chinese gardeners in Changi, near Singapore, where for years the plants were grown and selected. The selections were made by the gardeners on the basis of the toxicity of aqueous extracts of the fresh root to various insects. The Goodyear Rubber Plantation Co. brought 60,000 cuttings of this Changi variety to their Wingfoot estate in Sumatra in 1932. From a survey of the leaf characters they concluded that the plants were not a single clone; therefore, 200 of the plants were tagged for observation and about half of the roots removed for analysis. Dr. Ten Broeck, chemist with the Goodyear Rubber Plantations Co., found that a graph of the frequencies at which the different rotenone percentages occurred against the rotenone percentages resulted in a tri-modal curve with peaks at 3-4 per cent., 7-8 per cent., and 10-14 per cent. Hence, he concluded that the 200 selections fell into 3 classes according to rotenone percentages; low, medium, and high. This indicates that the native gardeners in Changi had only mediocre success with their selection technique. Dr. Bangham took 13 clones of the high-rotenone group to Panama in 1935 for further propagation. This station was fortunate to obtain cuttings from 9 of these 13 clones in March, 1940. A field planting was made in November, 1940 in a heavy black soil which had a relatively high water table that provided for the longest possible growing season. Eight plants of inferior *Derris* of the Sarawak Creeping variety were planted between each

Changi No. 3 plant. All plants were spaced 3 feet apart and grown on trellisses set at 4-foot intervals. The high-rotenone clones were shield-budded on the inferior stock, thus producing a maximum amount of cuttings for further propagation.

The nine clones were originally numbered in accordance with those tested at the Goodyear plantation in Sumatra. For simplification and to avoid confusion with numbers assigned by other workers having material from the same source, the clones were later renumbered from 1 to 9 in the decreasing order of rotenone percentage as found in the second evaluation study herein reported. The code letters MG (Mayaguez-Goodyear) were placed before each number.

After the plants were in the field 18½ to 21 months, approximately half the root systems were excavated from 3 plants of each clone. This operation caused no apparent injury to the plants. The fresh roots were separated into diameter groups as follows: 6.0 per cent. were less than 2 mm.; 17.3 per cent., 2.0 to 4.9 mm.; 46.6 per cent., 5.0 to 9.9 mm.; 25.9 per cent., 10.0 to 14.9 mm.; and 4.2 per cent., 15 mm. or larger. After drying, the roots of each plant were ground and analyzed, thus giving for each clone 3 replicates of 1 plant each. The data are tabulated in Table 1.

**Table 1**

**Mean rotenone percentage, dry basis, in *Derris elliptica* Changi No. 3 clones**

| Clone | Rotenone |
|---|---|
| *Number* | *Per cent.* |
| MG-1 | 8.8 |
| MG-5 | 8.6 |
| MG-6 | 8.6 |
| MG-2 | 8.0 |
| MG-4 | 8.0 |
| MG-7 | 7.4 |
| MG-9 | 7.3 |
| MG-8 | 7.0 |
| MG-3 | 6.9 |

Difference necessary for significance— 2.6

Difference necessary for high significance—3.6

Maximum difference found—1.9

Although differences between means of the percentages of rotenone of the clones were as great as 1.9 per cent, the design of the experiment was such that the great variation among individual plants forced the conclusion that the differences among clones were not significant. The coefficient of variability (the standard deviation divided by the mean) was 19.3 per cent., which is indicative of an excessive experimental error, perhaps entirely due to the fact that each replicate consisted of only one plant. Since the evaluation was attempted only on the basis of rotenone percentage, yield data were not considered.

### Second Evaluation

A more complete evaluation experiment was made in 1944 with the same plants and with the others not previously sampled growing in the same area. After the tops of all the plants were removed and utilized for further propagation, the roots were excavated as completely as possible. However, each plant was not regarded as a separate sample. Instead, all of the plants in each clone were taken at random in three groups, each group containing from four to nine plants. Since the groups were made up at random from the population of the plants in each clone, each group was regarded as a replicate of that particular clone. The roots were graded as follows into diameter groups: small, up to 4 mm.; medium, 4 to 8 mm.; large, greater than 8 mm. After washing and drying the roots, the yield data were taken as the average number of ounces of dry root per plant.

The 9 clones were replicated 3 times and sorted into 3 sizes making a total of 81 samples. All of these were analyzed colorimetrically for rotenone plus rotenoids (4). The powdered samples of small, medium, and large roots were then composited in proportion to their yields to give 27 samples representing the 3 replications of each of the 9 clones. These 27 samples were analyzed for moisture, total chloroform extractives, rotenone, and rotenone plus rotenoids. Combining these results with the yield data, analyses of variance were made to find the significance of differences among clones on the basis of yield of root, and yield and percentages of rotenone and rotenone plus rotenoids.

In another earlier experiment *Derris* planted in this same heavy soil was noted to be lower than usual in rotenone percentage (5). Therefore, at the time of harvest of these clones a few plants of Sarawak Creeping variety were also dug so that, by comparison with other data for the Sarawak Creeping variety, the effect of this heavy soil on rotenone deposition might be estimated. In this trial the root of the Sarawak Creeping variety was again definitely of lower quality than the root of the same variety grown in lighter and better drained soil. In yield of root, the Sarawak Creeping variety appeared normal. This information indicated that the high-rotenone clones of Changi No. 3 may be expected to yield even higher quality root when grown under more favorable conditions.

The data for root yield are given in Table 2.

It can be seen that the highest yielding clones were superior to the lowest by high significance. One clone was outstandingly high and one was exceptionally low. The Sarawak Creeping variety in the same field averaged 13 oz. of root per plant while the Changi No. 3 was about twice that amount. In a previous varietal comparison (1) Sarawak Creeping produced 1,028 pounds of root per acre; therefore, by direct comparison, the Changi No. 3 should average about 2,000 pounds per acre.

**Table 2**

**Mean root yields per plant of nine Changi No. 3 clones***

| Clone | Roots per plant |
|---|---|
| *Number* | *Oz.* |
| MG-9 | 29.7 |
| MG-8 | 27.4 |
| MG-6 | 26.8 |
| MG-1 | 24.1 |
| MG-5 | 20.9 |
| MG-2 | 20.8 |
| MG-3 | 19.8 |
| MG-7 | 19.3 |
| MG-4 | 16.6 |

Difference necessary for significance—7.6

Difference necessary for high significance—10.1

| | |
|---|---|
| 9 > 5, 2, 3, 7, 4 | 9 < 7, 4 |
| 8 > 3, 7, 4 | 8 < 4 |
| 6 > 4 | 6 < 4 |

*The notation in the third section of this and succeeding similar tables is an abbreviated summary. By this means, highly significant and significant differences are pointed out. The sign < means "is (are) superior by high significance (1 per cent. level)" and > means "is (are) superior by significance (5 per cent. level)."

The yield of large roots was greater than that of medium-sized roots which, in turn, was greater than that of small. These differences were highly significant and were in the proportion 7.8 : 3.4 : 1 for large, medium, and small roots. However, there were no significant differences among the clones on the basis of the yield of small roots and of medium roots. Variations in total root yields among the clones were brought about chiefly by the great differences in yields of large roots. The order of the clones according to yields of large roots was, in general, the same as the order based on the total root yield. Comparison of the yield data showed that the Changi No. 3 variety yielded considerably more large roots than the Sarawak Creeping; therefore, if both varieties had been harvested at an earlier date, say 2 years after planting, the yields would have been somewhat closer to being equal. On the other hand, the rotenone percentage of the total roots of the Changi No. 3 variety probably would have been higher because less large roots which are usually poorer in rotenone than medium roots would have developed.

With regard to rank according to quality of root, approximately the same order was obtained whether the criterion of quality was percentage of rotenone or of rotenone plus rotenoids. Mean rotenone contents tabulated in Table 3 ranged from 6.6 to 8.0 per cent. with the higher values differing from the lower by high significance.

**Table 3**

**Rotenone percentages of nine Changi No. 3 clones***

| Clone | Rotenone |
|---|---|
| *Number* | *Per cent.* |
| MG-1 | 8.0 |
| MG-2 | 7.9 |
| MG-3 | 7.7 |
| MG-4 | 7.5 |
| MG-5 | 7.4 |
| MG-6 | 7.4 |
| MG-7 | 7.0 |
| MG-8 | 6.9 |
| MG-9 | 6.6 |

Difference necessary for significance—0.8

Difference necessary for high significance—1.0

| | |
|---|---|
| 1 > 7, 8, 9 | 1 < 7, 8, 9 |
| 2 > 7, 8, 9 | 2 < 8, 9 |
| 3 > 8, 9 | 3 < 9 |
| 4, 5, 6 > 9 | |

*The notation in the third section of this table is similar to that in Table 2.

The coefficient of variability, 11 per cent, for the rotenone values was not excessive. The Sarawak Creeping root averaged 4 per cent. of rotenone. Although rotenone analyses were not made for the root diameter groups of the 9 Changi No. 3 clones, colorimetric determinations of rotenone plus rotenoids showed that significant differences existed. Thus, in all clones it was found that small and medium diameter roots were about equal in rotenone plus rotenoids (14.4 per cent.) but that large root (11.6 per cent.) was poorer by a highly significant difference. These values correspond to calculated rotenone percentages of 7.1 and 5.7 respectively. Ranking of the clones within root diameter groups on the basis of the content of rotenone plus rotenoids was approximately the same in all three groups.

With regard to the yield of rotenone per plant (the rotenone percentage multiplied by the root yield), only the three highest clones were significantly better than the poorest clone. The Sarawak Creeping variety averaged 52 oz. of rotenone per 100 plants. The data are tabulated in Table 4.

Using the yield of rotenone plus rotenoids (percentage rotenone plus rotenoids multiplied by the root yield) the order of ranking was similar to the ranking on the basis of rotenone yield. This colorimetric criterion was applied to the root diameter groups also and it could be seen that, although no significant differences existed among the clones on the basis of yields of rotenone plus rotenoids in small or in medium diameter roots, there were significant and highly significant differences among clones in the quality of the large roots. In general, the large roots over 8 mm. gave the most rotenone plus rotenoids; the medium

**Table 4**

**Rotenone yield per 100 plants of nine Changi No. 3 clones**

| Clone | Rotenone yield |
|---|---|
| *Number* | *Oz.* |
| MG-6 | 197 |
| MG-9 | 196 |
| MG-1 | 193 |
| MG-8 | 190 |
| MG-2 | 163 |
| MG-5 | 154 |
| MG-3 | 151 |
| MG-7 | 134 |
| MG-4 | 123 |

Difference necessary for significance—70
Difference necessary for high significance—96

6, 9, 1 > 4

roots were second in rank and the small roots last. These differences were highly significant. Hence, while it was true that the large roots were somewhat poorer in quality than the smaller ones, the bulk of the rotenone produced by the plant was in the large roots. The amounts of rotenone in the large, medium, and small roots were in the proportion of 6.2 : 3.4 : 1. Therefore, the practice sometimes recommended in the literature of discarding the large roots is not sound.

### Quantity-Quality Correlation

These data on the quantity and quality of roots show that, in many cases, the clones which had the highest root yield were lowest in quality and vice versa. This observation suggested an inverse correlation between yield and quality. Less rotenone appears to de deposited when carbohydrates are being accumulated, and conversely, more rotenone appears to be deposited when there is minimal carbohydrate accumulation. The possibility of such an inverse relationship is further indicated by the fact that starch and rotenone exist in separate cells in the root (6).

In order to determine whether such a relationship existed, correlation coefficients between quality and quantity were calculated.* For the 27 samples (3 replicates of 9 clones), the correlation coefficient of 0.137 between the root yield and rotenone percentage was not significant; therefore, root yield and quality were neither positively nor negatively correlated. However, the correlation coefficient between yields by root-diameter groups and quality (expressed as the rotenone plus rotenoids percentages) calculated from the 27 items (3 sizes each of 9 clones) was $-0.772$, a highly significant negative correlation; in other words, quality decreased as the root diameter increased. This relation was so marked that when the whole array of 81 items (3 root diameter sizes of each of 3 replicates of 9 clones) was used a highly significant correlation coefficient, $-0.643$, was found; this was due to the fact that the effect of root diameter was not removed. When this effect was removed by considering only the 27 items (3 replicates each of 9 clones) without separation into root diameter groups, the correlation coefficient of $-0.339$ was not significant. This correlation between yield and quality as expressed by rotenone plus rotenoids agreed with the above correlation between yield and quality as expressed by percentage of rotenone in that no correlation was found in spite of the fact noted earlier that high yields are generally caused by a greater proportion of large diameter roots which are poorer in rotenone.

Additional calculations were made of the correlation between root yields and quality (expressed as rotenone plus rotenoids percentage) within root diameter groups. Considering only the small-diameter root, the correlation coefficient of 0.125 was not significant; likewise for the large-diameter root, the coefficient of $-0.217$ was not significant. However, when only the medium-diameter root was considered the coefficient of $-0.469$ was significant. The following considerations serve to clarify this point: it is well known that the growth curve of a plant is roughly sigmoidal; thus, plotting the amount of root against time results in a sigmoidal curve (Figure 1). The amount of root increases with time; the initial rate is low but increases markedly as the plant develops. Then, as the plant becomes large, the rate of growth decreases again. If a curve showing the quality index is superimposed on this growth curve there is found to be a rather high plateau at the left with a corresponding somewhat lower plateau at the right (shown by the dashed curve in Figure 1.) The quality of the root in the young plant when the mean diameter is small is represented at the left and that of the old plant having a large mean diameter at the right. In these portions the curves are drawn so as to be relatively parallel because it was found that there is no correlation between the amount of root and quality. However, to connect the two plateaus, a line more or less straight must be drawn and this line forms an X with the growth curve. This explains the observation that for roots of medium diameter there is a negative correlation between quantity and quality. If in our experiment the roots had been judiciously graded into the correct diameter groups so that the groups would more closely correspond with the picture as it occurs in nature, this phenomenon might have been brought out even more clearly. Nevertheless, the data viewed in this manner show what is meant by the observation that root yield and root quality are inversely proportional.

### Correlation between the two evaluation trials

Since two separate evaluations were made on the same groups of plants, it is possible to compare the results. These same nine clones were ranked twice on the basis of rotenone percentage and,

* Whether correlations or regressions were calculated for the data in these paragraphs, the conclusions were the same.

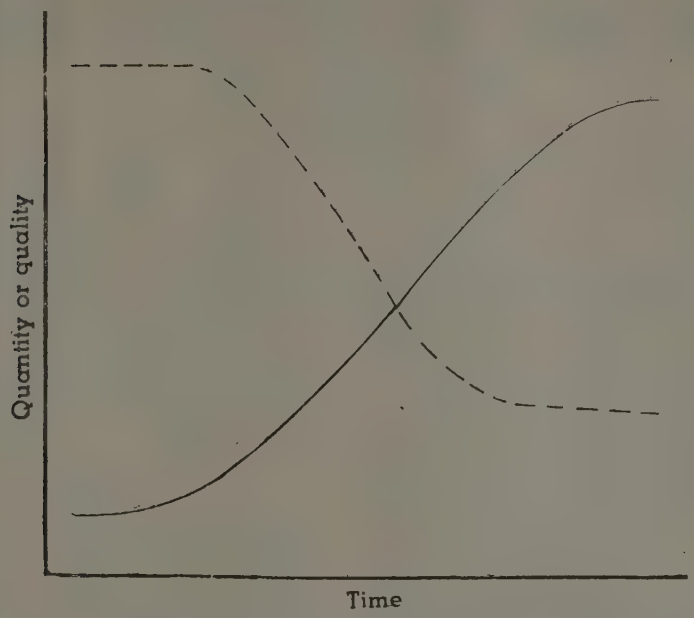


Figure 1.—Graph showing the change of amount of root produced (yield, solid line), and the quality index (dotted line) with the time during which the plant grows.

therefore, if this quality index is truly a clonal characteristic, and provided that no external factors acted strongly enough to change the order of quality, the two evaluations should be in substantial agreement. It is further assumed that valid conclusions can be drawn from a correlation between 9 pairs of data. As a measure of this agreement the correlation coefficient was calculated for the two sets of rotenone percentages given in Tables 1 and 3. The value, 0.52, was not significant. However, since the greatest source of error appeared to be in only one clone, MG-3, data for this clone were tentatively omitted on the argument that a gross error was made in the testing of this clone in one or the other evaluation trials (probably the first in view of the fact that the experimental error was great in that trial). If this omission is permitted, the correlation coefficient for the remaining eight clones, 0.768, was significant. Thus, substantial agreement was obtained between two evaluation trials with eight clones of one variety.

## Summary

In this study the criteria upon which the value of *Derris* clones can be based were discussed. The main consideration at present, with certain limitations, should be yield of rotenone per plant or per acre and secondary desiderata should be quality and yield of root.

The possibility of ranking clones of a variety of *D. elliptica* was explored with the result that, with the proper experimental design, it was found possible to show significant, as well as highly significant, differences among clones.

In the selection work on this material several stages have been realized. The original choices were made by the Chinese gardeners in Changi. The second segregations were made at the Goodyear plantation in Sumatra where again low-rotenone selections were discarded. At this station nine clones of the best Goodyear selections were evaluated twice. The first ranking made at the time the plants were 2 years old, was found to agree fairly well with that made in a complete harvest after the plants had been in the field 4 years. Further confirmation of the ranking obtained remains to be done, especially under conditions in which large scale production is anticipated.

It was shown that the large roots contained the major portion of the rotenone present in the root system.

A discussion is given of the inverse relationship between root yield and quality.

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# STUDIES OF DIURNAL VARIATION IN THE BODY TEMPERATURE OF THE TROPICAL THREEQUARTER BRED (HOLSTEIN-ZEBU) DAIRY CALF

BY

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Diurnal variation in body temperature has received but little attention. A small number of studies of the variation in birds has been reported by Brody (1945) and various workers have referred to differences between day and night body temperatures. The problem is not one of great interest to physiologists working in temperate zones since, under their conditions, variations in body temperature during the day are only slight.

That the magnitude of variation might be greater under tropical conditions is suggested by the findings of Rhoad (1940). In his studies of the changes in body temperature of adult beef-cattle exposed to direct sunlight considerable increases were observed in certain types of animals. The rise in temperature was most marked in pure-bred Aberdeen Angus cattle where an average level of 107.5°F was reached. Similar but slightly less severe increases were observed in threequarter-bred cattle (the first backcross to Aberdeen Angus of Angus-Zebu half-bred cattle). Only small increases occurred in the temperature of pure-bred Zebu while half-bred cattle (the $F_1$ hybrid of Zebu and Aberdeen Angus) were only slightly more affected. No study was made of the night period.

These findings are of considerable importance in the case of beef cattle under shadeless range conditions as a guide in developing heat tolerant beef breeds for the tropics. Rhoad (1942), having this in mind, extended his studies using the magnitude of the increase in body temperature as the basis of calculating an index of heat tolerance. The formula for calculation was :

Heat tolerance index $= 100 - 10\ (BT - 101.0)$ where BT represents the body temperature of animals exposed to direct solar irradiation on days when shade atmospheric temperatures were in the 90°F class. The tentative indexes for various breeds and cross-breeds were as follows :

| | |
|---|---|
| Pure-bred Zebu | 93 |
| ½ Zebu—½ Angus | 89 |
| Pure-bred Jersey | 86 |
| ⅜ Zebu—⅝ Angus | 86 |
| ½ Africander—½ Angus | 83 |
| Pure-bred Santa Gertrudis | 82 |
| ¼ Zebu—¾ Angus | 76 |
| ¼ Africander—¾ Angus | 75 |
| Grade Hereford | 73 |
| Pure-bred Aberdeen Angus | 56 |

In the case of tropical dairy cattle the nature of the problem may be different. Milk production is normally practised under conditions where the provision of natural or artificial shade for stock is not difficult. It seemed important, therefore, to determine the course of body temperature during the entire day under such conditions of management as appear to be reasonably satisfactory for tropical dairy stock.

It is clear from Rhoad's indexes given above that the genetic background plays an important rôle in determining heat tolerance. For that reason attention was devoted to animals of threequarter Holstein ancestry. An additional reason for studying threequarter-bred animals is that they represent the early stages in a breeding programme designed to develop a tropical dairy breed by crossing within this type and selection from the offspring.

## Method

Body temperatures were taken rectally at a standard depth of four inches. The thermometer was held in place for a period of two minutes. All thermometers were tested to ensure that body temperature was accurately recorded in less than this interval. Although Kriss (1921) found that posture had little effect upon the rectal temperature of cattle all observations were made with the animals standing. If defecation began during taking of the temperature the observation was repeated.

The calves used in the experiments described below were cross-bred between Holstein-Friesian and the Nellore type of Zebu. They were principally threequarter-bred animals although some contained less than one quarter of Zebu blood. These animals have been developed by back-crossing, to pure-bred Holstein-Friesian bulls, females whose parents were a pure-bred Holstein-Friesian bull and a Nellore Zebu dam. In some cases the records of the Zebu grand-dams were not available and some doubt existed as to their being pure-bred. Only heifer calves were studied.

Wet and dry bulb temperatures were taken hourly during all experiments and the relative humidities calculated.

*Experiment* 1.—In this experiment a group of ten calves was selected from a larger group which was being studied to investigate the nutritional requirements of the cross-bred calf for normal growth. They were of different ages being between six and thirty-six weeks of age. In health they were normal and shewed rates of growth similar to those of pure-bred temperate zone calves.

Body temperatures were recorded hourly throughout the day and night on five days. These days were not consecutive but distributed through part of the wet season (June, July and August).

On three of the days the calves were under the normal routine of calf management practised at the College Farm. During the period from 8 a.m. to 11 a.m. the calves were in a savannah grass (*Axonopus compressus* (Sw.) Beauv.) paddock which had light shade from coconut palms.

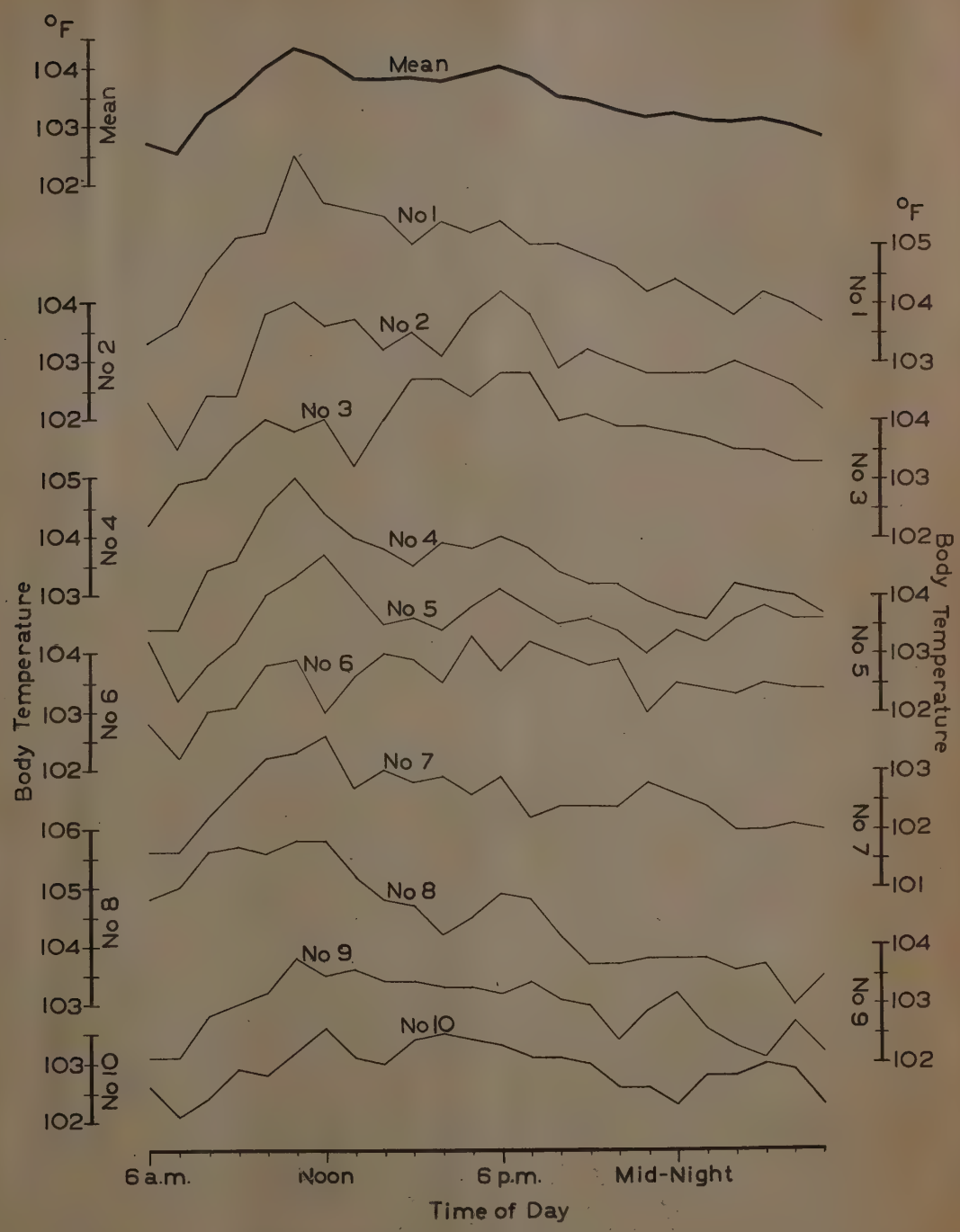


Figure 1. Diurnal variation in the individual body temperatures of ten calves under normal management, together with the average of the group.

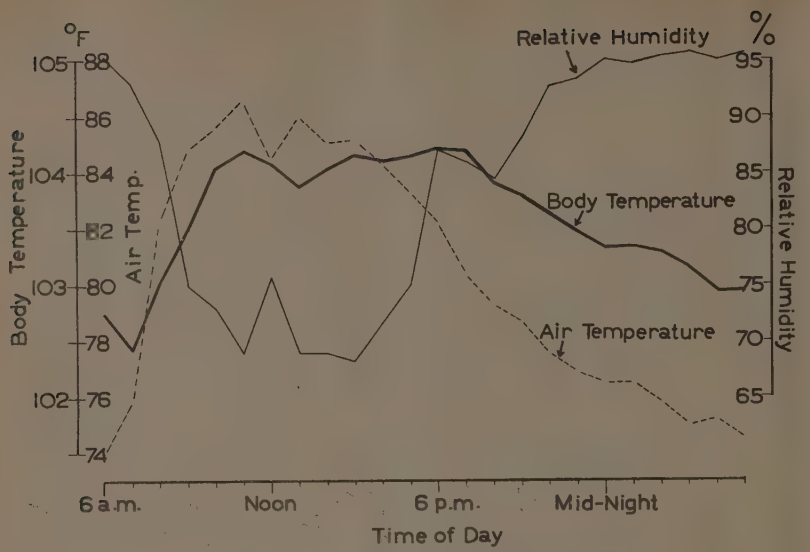


Figure 2. Diurnal variation in the average body temperature of the group of ten calves during the three days when they were under normal management, together with the average shade atmospheric temperature and relative humidity.

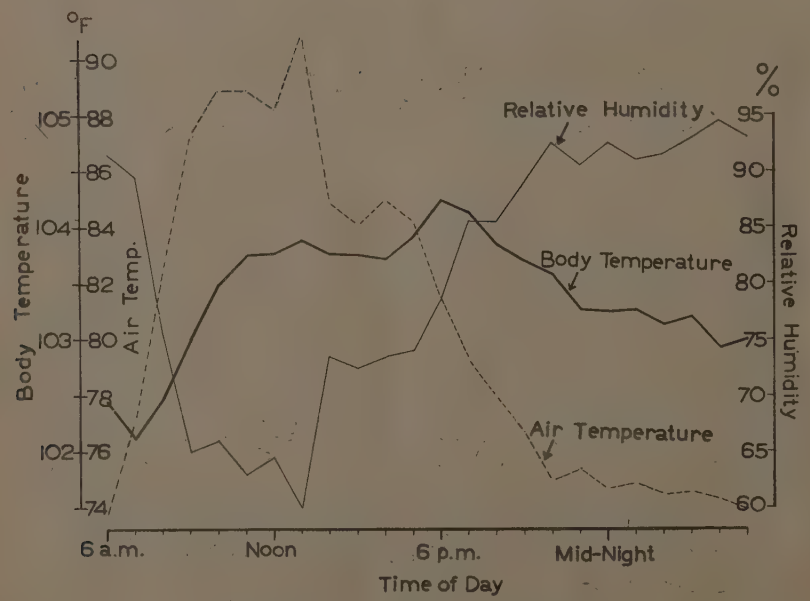


Figure 3. Diurnal variation in the average body temperature of the group of ten calves during the two days when they were kept in roofed pens throughout the day, together with the average shade temperature and relative humidity.

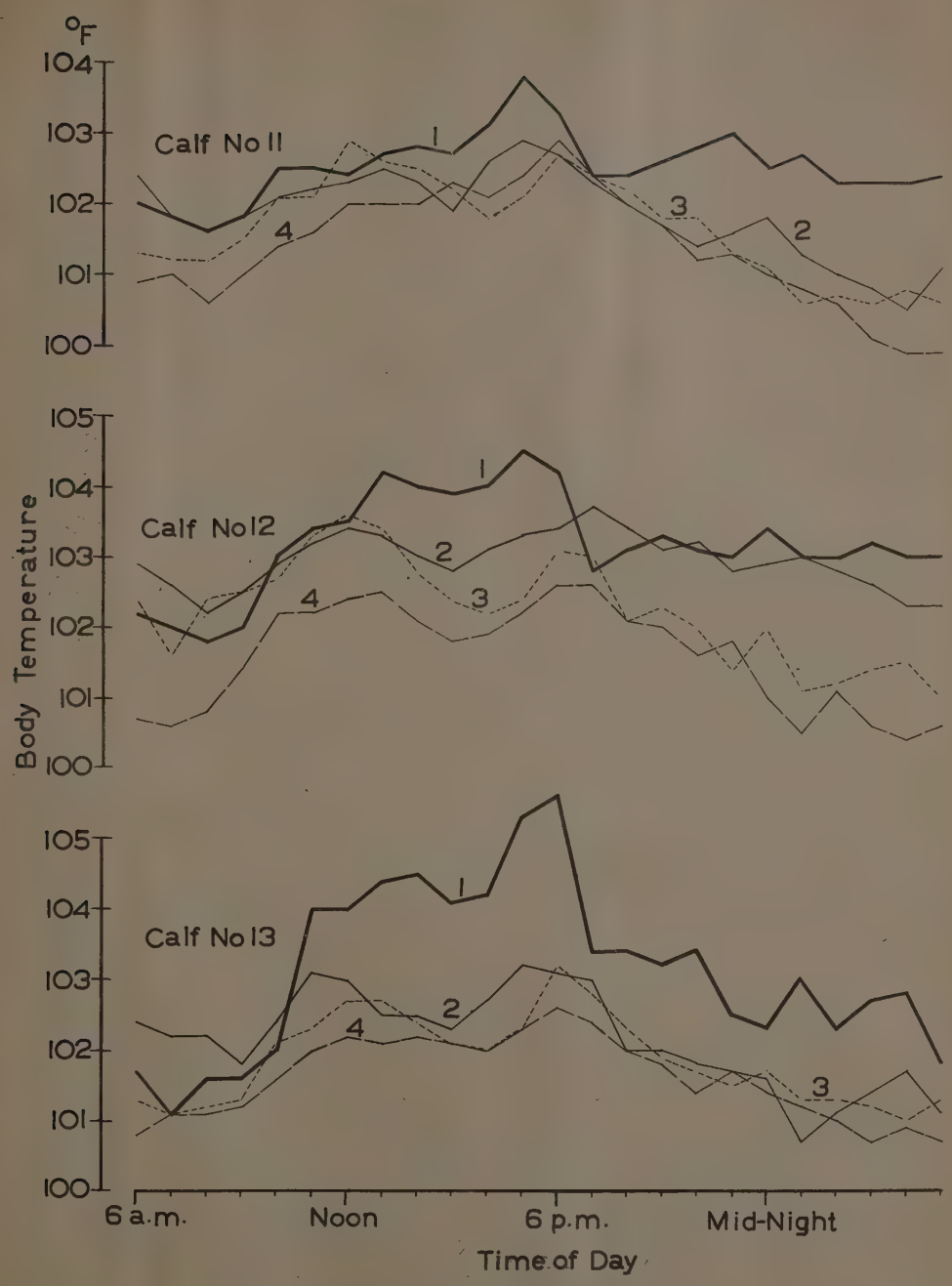


Figure 4. Diurnal variation in the individual body temperature of Calves 11, 12 and 13 during the starvation experiment. In each case Curve 1 represents the first day of the experiment when the normal feed allowance was given, Curve 2 represents the first day of starvation, Curve 3 the second day of starvation and Curve 4 the third day of starvation.

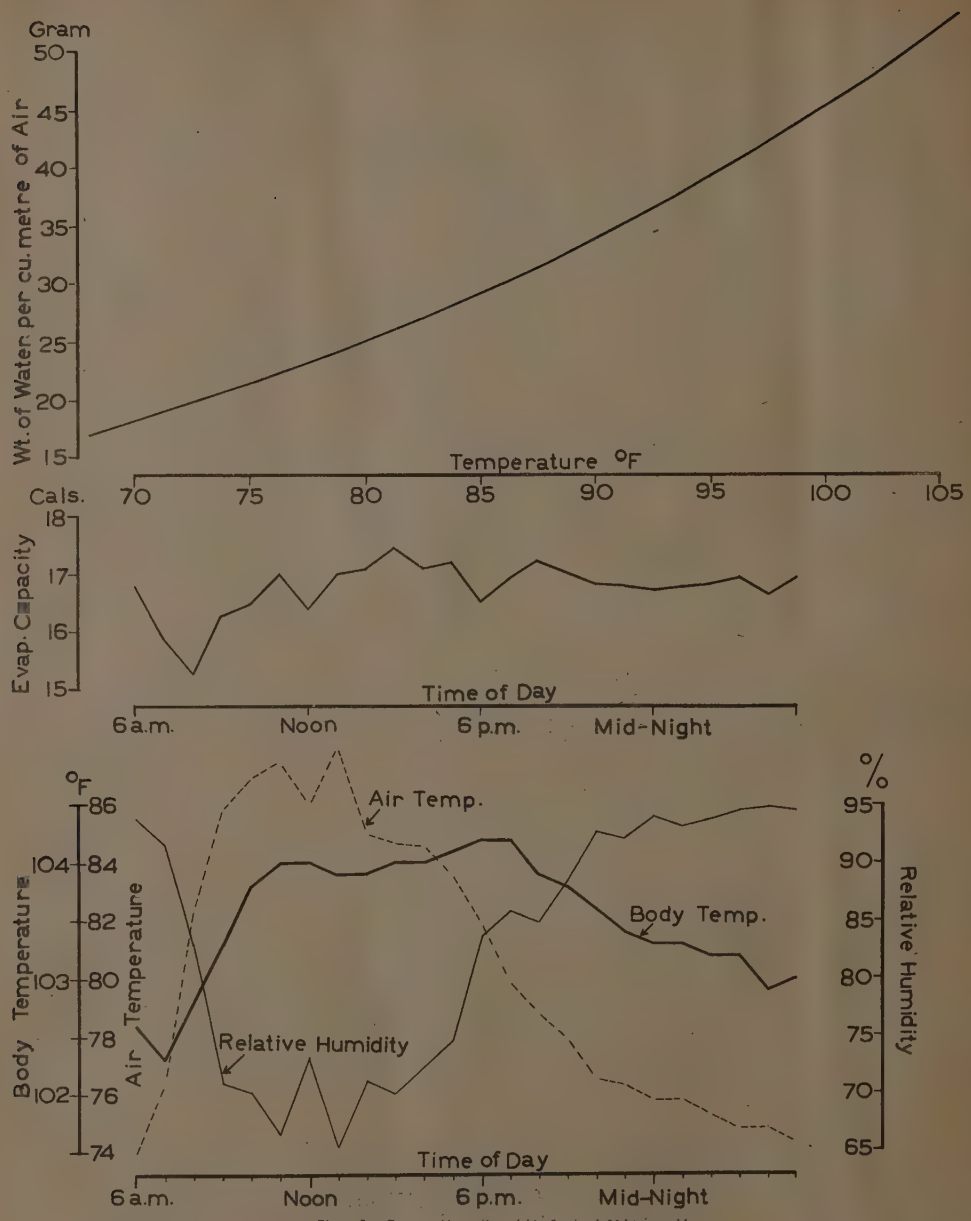


Figure 5. Upper portion: the weight of water held by one cubic metre of saturated air at different temperatures. Lower portion: diurnal variation in body temperature. Shade atmospheric temperature and relative humidity obtained by averaging the data of Experiment 1. Central portion: diurnal variation in the evaporating capacity of the atmosphere expressed as Calories of heat dissipated in saturating one cubic metre of atmospheric air (at the prevailing shade temperature and relative humidity) with water in the lungs (at prevailing body temperature).

During the rest of the day they were housed in roofed concrete pens with concrete floors and adequate supplies of bedding. Grass was before them in racks at all times and at 11 a.m., the concentrate allowance was given in feeding troughs in the pens. In the case of younger animals the concentrates were eaten gradually throughout the day. With older animals the relatively limited concentrate allowance was consumed more rapidly. Fuller details of the management will be published elsewhere (Duckworth, McWilliam and Rattray). On the remaining two days the animals were managed as above except that no access to the paddock was allowed, the animals remaining in the pens throughout the day.

*Experiment* 2.—Three animals of breeding similar to that of the calves studied in Experiment 1 were used in Experiment 2. Hourly observations were made of body temperature for four consecutive days. During the first day the animals were under normal management and feeding except that they were kept in the pen under shade. During the second, third and fourth days the animals were retained in the pen as on the first day but no feed was given. Water was available at all times. Light muzzles which permitted drinking were worn during the three-day starvation period to prevent the calves from eating bedding. Canvas screens were used to exclude direct sunshine from the pen at all times.

## Results

The results obtained in Experiment 1 are presented in Figs. 1, 2, and 3. In Fig. 1 are recorded the individual diurnal body temperature curves of ten calves under normal management together with the curve derived by averaging the hourly temperatures. In Fig. 2 are recorded the average body temperature curves of the group during the three days when normal management was followed. In the case of each curve the corresponding atmospheric shade temperatures and relative humidities are also presented. In Fig. 3 similar information is given for the group of calves on the two days when they had no access to the paddock but were retained under shade all day.

The results for Experiment 2 are presented in Fig. 4, the individual body temperature curves of the three animals being shewn for the ninety-six hour duration of the experiment.

The body temperatures of the individual calves presented in Fig. 1 shewed a sharp rise in each case. The increase began at 6 or 7 a.m. and continued until a peak value was recorded at 11 a.m. or noon. The magnitude of the increase differed from one animal to another. In some cases the increase was marked as in calf No. 1 where the body temperature rose from 103.3°F. at 6 a.m. to 106.5°F. at 11 a.m. In other cases the increases were less severe; calf No. 8 shewed an increase of only 1°F. between 6 a.m. and 11 a.m. This animal had, however, an initial temperature of 104.8°F. at the beginning of the study. The average increase of the group was 1.8°F.; from 102.6°F. at 7 a.m. to 104.4°F. at 11 a.m.

The course of the body temperature after mid-day was not so uniform from animal to animal as had been the course before mid-day. In all cases throughout the present, and other, investigations there was a recession after mid-day. In most of these cases the recession was followed by a second period of elevated temperature in the late afternoon or early evening. Of the cases presented in Fig. 1 this is indicated in Nos. 2, 3, 4, 5, 6, 8 and 10. In Nos. 1, 7 and 9 its existence is in doubt. The average curve in Fig. 1 shews the recession after mid-day and the secondary peak at 6 p.m.

During the remainder of the day, from 6 p.m. to 5 a.m., the body temperature gradually declined. In most calves a value similar to the initial temperature was reached. Some animals, as No. 3, failed to reach the previous morning's level by 5 a.m. Others, as in the case of No. 8, shewed temperatures below the initial level.

The atmospheric data presented in Figs. 2 and 3 shew that shade temperature and relative humidity follow a similar course from day to day. During early morning the atmospheric temperature rose sharply and relative humidity fell. During the hours around noon atmospheric temperature remained high and relative humidity remained low both values fluctuating over a relatively narrow range. Broadly speaking temperature and relative humidity varied inversely.

The mean body temperature curve presented in Fig. 2 shews that on the days when management followed the normal routine the body temperature rose sharply during the morning, receded slightly after mid-day, rose to a secondary maximum during late afternoon and returned to the initial value during the night. The general course of the curve for the days when the animals had no access to the paddock, but were kept penned in shade all day, is not seriously different. The average increase of the animals under normal management (Fig. 2) was 1.8°F., rising from 102.4°F. at 7 a.m. to 104.2°F. at 11 a.m. The average increase of the animals penned under roof (Fig. 3) was 1.8°F., rising from 102.1°F at 7 a.m. to 103.9°F. at 1 p.m.

Experiment 2 was undertaken primarily to investigate the influence of feed upon the nature of the diurnal rhythm. The data are recorded in Fig. 4, the diurnal changes being given for each animal individually.

On the first day of this experiment, when the animals were given their full feed allowance, the rise in body temperature occurred as in the previous study. The first maximum was not well defined but the second maximum at 5 to 6 p.m. was clearly demonstrated.

During the three starvation days elevation of the body temperature followed by recession to give the first maximum was shewn daily by each animal except, on the final day of the experiment when Nos. 11 and 13 shewed no recession. In all cases the second maximum occurred and, except in two observations, was higher than the corresponding first maximum of the same day.

The body temperature curves during the starvation period were displaced below the corresponding curves for the day when feed was given.

## Discussion

Before discussing the observations made on the hyperthemia* observed in the tropical dairy calf the heat exchanges between animals and their environment will be examined, with special reference to the tropics. Although the amount of information on the physiological response of animals to tropical conditions is limited much of the knowledge established for temperate zone animals is directly applicable.

Exchanges of heat require consideration from three standpoints : that of heat production by the animal as a consequence of metabolism, that of heat dissipation by the thermoregulatory mechanisms of the animal and that of environmental, or climatic, circumstances. The subdivision of factors influencing thermal equilibria into these categories does not imply independence. The contrary is true. The nature and the magnitude of activity of the thermoregulatory mechanisms are conditioned by the metabolic rate on the one hand and by the environmental conditions on the other. In addition heat may arise in the body by absorption of radiant energy from the environment thus increasing the burden placed on the mechanisms of thermoregulation.

For some purposes these energy exchanges are conveniently studied by body temperature measurement, an increase in temperature reflecting a net gain in heat by the organism and a decrease reflecting a net loss. Constancy of body temperature could only be attained if the rate of dissipation of heat were at all times equal to the rate of heat production. Over long periods of time this condition repeatedly arises in that body temperature always returns to a previous level, all the heat arising during the interval having been dissipated. Within short intervals of time, as from hour to hour, equilibrium between thermogenesis and thermolysis is not attained and a diurnal rhythm in body temperature results.

The literature on diurnal rhythm is not extensive. Brody (1945), summarizing the available information, concluded that body temperatures are minimal during night, that is at times of relaxation and sleep, and maximal during late afternoon. There was some evidence that experimentally reversing the light rhythm so that sleep occurred during daytime and activity during night led to a reversal of the body temperature rhythm. Similarly, Kriss (1921) observed that the body temperature of the cow rose during the afternoon to reach a higher level at about 5 p.m. Since this transitory partial retention of heat occurs under temperate zone conditions, where environmental circumstances facilitate rather than impede heat dissipation, it is improbable that it arises from a functional inadequacy of the thermoregulatory mechanisms to eliminate heat at the same rate as that at which it is produced. It is difficult to propose any obligatory relation between this rhythm and the diurnal rhythm in metabolism discussed below.

In the present discussion no attention is given to the temperature gradient existing in the body. Rectal temperature is treated as representative of the body as a whole although it is recognized that the temperature is higher in an organ as active, metabolically, as the liver. Similarly the slight daily positive heat balance arising from the daily weight increment is neglected.

### The Heat of Metabolic Origin

Body heat originates from metabolism within the tissues of the organism, from the metabolic activities of the microflora of the alimentary tract and from the acquisition of heat from the environment, both by conduction and by the absorption of radiant energy. For present purposes attention need not be given to that fraction of the total heat arising from the activity of the alimentary microflora. It is not great in amount and varies only slightly from one animal to another of a given species under comparable conditions. The heat acquired from the environment is discussed below.

The quantity of heat produced as an end product of tissue metabolism is not constant from hour to hour but varies regularly throughout the day. The observed diurnal rhythm in total metabolic heat production arises through the summation of three independently varying contributory sources : the basal metabolism, the activity metabolism and the increased metabolism arising through the thermogenic action of food. The basal metabolism (the energy cost of maintaining essential life processes uncomplicated by the energy demands for movement) is generally thought to be minimal during night. Owing to technical difficulties it is impossible to determine with accuracy the diurnal variation in the basal metabolism of the normal ruminant. The activity metabolism (the metabolism necessary to provide the energy for movement, including the prehension, mastication and digestion of food and the propulsion of the ingesta through the alimentary canal) is much greater during daytime than during night. The thermogenic action or specific dynamic action of food (the stimulus to heat production arising from the presence in tissues of absorbed nutrients) is maximal after the processes of absorption are completed ; as most types of domestic animals receive the greater part of their rations during daytime this increase in heat production occurs principally during the day period. The thermogenic action of food extends over a much greater proportion of the day in ruminants as compared with non-ruminants, owing to the continued passage of materials from the rumen during the night.

* The convention suggested by Lusk (1928) is adopted : that the term " fever " should be restricted to those increases in body temperature that result from the invasion of the animal by pathogenic organisms and that temperature increases otherwise occasioned should be known as " hyperthemias ".

The combined effect of the three variables is to characterize the daytime, and probably the early evening, as the period of most intensive heat production while the night is the period of minimal heat production.

### The Acquisition of Heat from the Environment

Heat is acquired from the environment by the absorption of radiant energy and by conduction. If the air temperature rises above the surface temperature of the animal heat is also gained by convexion. The acquisition of heat by conduction is rare and, even in the tropics, relatively meagre in amount. Conversely, the amount of heat acquired by absorption of radiant energy may reach high levels, especially in tropical zones.

The contribution made to body heat by absorption of radiation has received little attention, probably because it does not present a serious problem in temperate zones. Recently the South African workers at Onderstepoort have undertaken a systematic investigation of the problem.

The incoming radiations are the direct solar beam and the scattered radiation from the sky, about 90 per cent. of the radiation received being from the direct beam. Riemerschmid (1943) found that about 30 per cent. of the incoming radiation was reflected from the earth's surface, the value being slightly lower for bare sand than for grass.

The intensity of radiation measured at right angles to the solar beam varies throughout the day. At sunrise and sunset the distance traversed through the terrestrial atmosphere by the incoming beam is maximal while at noon solar time the distance is minimal, the relative values for air mass at angles of solar culmination of 90°, 60°, 30° and 15° being 1.0, 1.15, 2.0 and 3.8 respectively. Consequently the quantities of solar radiation absorbed by the atmosphere are least at mid-day and greatest in the early morning and late afternoon. Similarly the intensity of radiation varies from month to month throughout the year as the angle of culmination of the sun progressively changes.

The changes in radiant energy transmissions during the day are: first, an increase in intensity of incoming radiation to reach a maximum at noon solar time, followed by a decrease; second, changes in reflected radiation which probably vary in a parallel manner with total incoming radiation; third, an increase in radiation from the earth's surface and buildings as their temperatures are raised through the absorption of incoming radiation, thereafter followed by a decrease. The third source will continue to transmit long wave radiation after the first two sources have finished owing to the difference in temperature between the earth's surface, including buildings, and the atmosphere. The total effect is a rapid increase to reach a maximum at about noon solar time followed by a slower rate of decline. Quantitatively the total radiation received changes progressively from day to day as the angle of culmination of the sun at noon solar time alters. It also varies with the occurrence and density of cloud.

Riemerschmid (1943) calculated the quantity of radiation absorbed by brown coated South African cattle. The heat equivalent of the radiation absorbed during the hours of daylight was almost three times as great as the total heat of metabolism produced during a twenty-four hour period. It follows that during the middle part of the day the ratio of heat of radiant origin to heat of metabolic origin must have been much greater.

It will be noted that the period of greatest radiation intensity occurs during the period when the production of heat by metabolic processes is also at its highest level.

### The Dissipation of Body Heat

The pathways of thermolysis are: first, by evaporation of water from body surfaces, including the internal surface of the lung; second, by long wave radiation; third, by convexion; fourth, by conduction; fifth by raising the temperature of inspired air and ingesta to body temperature. Only small quantities of heat can be dissipated by conduction (except in wallowing animals such as water buffalo and swine) and by raising the temperature of food, water and inspired air to body temperature, particularly in the tropics. Further attention need not be given to them. Losses of heat by convexion are relatively small in amount under temperate zone conditions and diminish as air temperature increases.

Losses of heat by radiation occur only when the temperature of the environment is below that of the surface of the animal. As environmental temperature approaches that of the animal's surface losses by radiation diminish and finally cease. If the temperature of structures in the animal's environment rises above that of the animal's surface, owing to absorption of solar radiation, heat is gained by the animal. The skin temperature itself, is subject to variation normally being below the internal temperature of the body. Riemerschmid and Quinlan (1941) found that the mean skin temperature of cattle averaged 33.6°C for atmospheric temperatures of 10° to 25°C and 36.5°C for atmospheric temperatures of 25 to 40°C. While the increase in skin temperature increases the temperature gradient between the animal's surface and the environment, the change is relatively small and can have little effect, quantitatively, upon radiation transfer of heat.

When conditions arise so that radiation losses are abolished or, as described above, when the body acquires heat by absorption of radiation the burden of thermoregulation falls almost entirely on the water evaporating capacity of the animal. The sensivity of the equilibrium between different routes of heat transfer is indicated in the summary of Leitch and Thomson (1944) who collected the available information about changes in water evaporation with increases in air temperature under temperate zone conditions. At atmospheric

temperatures of about 10°C approximately 20 per cent. of the heat produced was dissipated by water evaporation. At temperatures of about 20°C approximately 40 per cent. was eliminated by evaporation.

The organism evaporates water from the skin surface and from the lining membrane of the mouth, nostrils, trachea, and the air ducts and air cells of the lungs, about 580 Calories being dissipated as latent heat of vaporization for each litre of water evaporated. Although various writers have discussed the rôle of vaporization of water at body surfaces in tropical animals some confusion seems to have arisen through failure to recognize that while man and horsekind possess the faculty of profuse sweating cattle do not. In man the rate of water evaporation from the skin surface gradually increases as air temperatures rise until the so-called "critical" temperature of 29°C (range 27° to 32°C) is reached when the sweat glands secrete large quantities of sweat. The same condition appears to arise in horsekind (Adolph and Dill, 1938). It was shewn by Whitehouse, Hancock and Haldane (1932) that the water passing across the skin below the critical temperature was not of sweat gland origin. This water, which they regarded as osmotic or diffusion water, was produced in increasing amounts with progressive increases in air temperature and they attributed the enhanced secretion to enlargement of the peripheral vascular bed.

Freeborn, Regan and Berry (1934) extended these studies to dairy cattle. In their investigations they washed the skins of their experimental cows before and after exposure to different temperatures and analysed the washing liquid to determine the amount of sodium chloride excreted during the interval as an index of sweat production. The quantities found were extremely low. Cattle exposed for two hours to a temperature of 85°F. yielded 47 milligrams of sodium chloride per square metre of skin surface. Those exposed for the same period to 115°F. yielded 45 milligrams per square metre. Other measurements of the quantity of water evaporated from the skin of these cattle shew, on re-calculation, that about 187 cubic centimetres of water were evaporated per square metre of surface in two hours of 84°F. Taken in conjunction these findings indicate that the greater quantity of water evaporated from the skin of cattle is of osmotic rather than sweat gland origin. They also suggest that the successive increases in the quantity of water evaporated with progressive increases in air temperature, observed by Rhoad (1940), may not have arisen from increased sweat gland activity but from increases in the passage of osmotic water across the skin.

The extent to which the increased burden of heat dissipation is partitioned between skin evaporation and lung evaporation during periods when radiation and convexion losses are minimized is unknown. That much of the burden is borne by the alveolar surfaces is shewn by the increased respiratory rate of cattle during times of high temperature. Kleiber and Regan (1936) have shewn that the increased rate of respiration is accompanied by a decreased depth of respiration. In addition Regan and Richardson (1938) have shewn that pulse rate declined as atmospheric temperature increased. The reduction in depth of respiration together with this decreased rate of passage of blood through the lungs prevents excessive removal of carbon dioxide from the blood. This defence against lowering the blood carbon dioxide tension permits a sustained stimulus to the respiratory centre and an enhanced evaporation through the lungs.

## Present Findings

The course of body temperature in the type of tropical dairy calf used in the present study and under conditions of management similar to those existing in certain Trinidad herds can be divided into three phases: the morning phase, the afternoon phase and the night phase.

The morning phase begins about one hour after sunrise. All animals shew a marked rise in body temperature to reach a maximum at 11 a.m. or noon. During this period the metabolic heat production is increasing. Similarly the intensity of solar radiation is increasing with a consequent increase in heat generated at the animal's surface. Simultaneously the temperature of the environment is rising thus reducing the radiation of heat by the animal. The imbalance between thermolysis and thermogenesis is more severe at this time than at any other, judging by the rapid rate of increase of body temperature.

The afternoon phase is essentially a period of maintained hyperthemia. Mean values indicate a slight recession in temperature after the noon maximum followed by an increase to reach the evening maximum. Individual animals (Fig. 1) demonstrate this to different degrees or, in a few cases, not at all. Because the interactions of many factors determine body temperature this is to be expected. During this period the production of heat as a consequence of metabolism is probably sustained at a high level. The intensity of direct solar radiation to which the animal is subjected is very slight owing to their being housed under shade. However, a certain amount of solar radiation will continue to be received by reflection from the ground surface and from nearby buildings. The total quantity of radiation impinging on the animal will not, however, decline correspondingly owing to the secondary radiation from buildings which had previously been raised to a high temperature by the absorption of solar radiation and which continue to emit long wave radiation. The influence of the latter contribution will be to sustain the total radiation at a high but, probably, gradually falling level during the second phase.

The night phase is the period when body temperature falls to approximately normal levels. In some cases the ultimate level is well above the preceding initial morning level and in others it is considerably below it. The entire night period is required for body temperature to reach levels such as is considered approximately normal for calves in temperate zones.

As stated above studies of warm blooded animals in temperate zones indicate that the fundamental diurnal rhythm in body temperature is characterized by a peak value in late afternoon. The present study shews that the same phenomenon occurs in tropical animals. The earlier portion of the curve is distorted as a consequence of the high concentration of radiant energy in tropical environments. This results in an average temperature curve characterized by two maxima in tropical animals. Because of the large number of factors influencing body temperature individual animals may not shew both maxima equally well defined on a given day.

That the type of cycle is influenced little by feed is demonstrated in the starvation experiment. In general the two maxima are more distinct during starvation than in fed animals. This is probably the result of reducing one source of heat, and therefore of variation, to a low level. The withholding of feed, by reducing the total quantity of heat to be dissipated by the overburdened thermoregulatory mechanisms, reduced the magnitude of variation and the temperature cycle did not rise to as high a level. It was felt, at one time, that the late afternoon temperature maximum was the result of the increased heat production consequent on feeding the concentrate allowance at 11 a.m. That this is not so is shewn by the persistence of the maximum during complete starvation.

The results of these experiments indicate that variations in the present system of management are unlikely to reduce materially the increase in body temperature. Little advantage is to be gained by housing the animals under roof during the middle of the day provided shaded paddocks are available as an alternative. The average increase in body temperature during the days when the animals were penned was the same as that observed when the animals were kept in coconut palm paddocks. The average air temperature was higher on the days when the animals were kept in pens and it is possible that a slightly greater increase might have occurred had they been in the paddock. The only advantage of roofed pens over shaded paddocks is a slight additional reduction in the quantity of direct radiation absorbed. It offers no protection from the radiation emitted by the heated environment, including the roof and pen itself. In addition it seems improbable that alteration in times of feeding would significantly reduce the degree of hyperthemia.

One aspect of thermoequilibrium of particular interest in the wet tropics is that of the influence of humidity on heat dissipation. It is generally held that the high humidity of the atmosphere is a serious obstacle to the evaporation of water at body surfaces. However, experimental evidence does not give support to this view. Mitchell and Hamilton (1936), Kriss (1936) and Leitch and Thomson (1944) found that the effect of variation in atmospheric humidity had an indefinite or only slight effect on water evaporation at body surfaces.

The problem of the influence of atmospheric humidity on heat dissipation by water evaporation cannot be considered in terms of humidity alone. Attention must also be given to the temperatures of the atmosphere and of the animal prevailing at the same time. The evaporating capacity of the air depends on the degree of saturation at a given temperature, that is upon the weight of water contained in a given volume of air compared with the total quantity that can be held at saturation at that temperature. As is shewn in the upper portion of Fig. 5 the quantity of water contained in saturated air increases in a curvilinear manner as temperature rises. On entering the lung inspired air is raised to body temperature and saturated with moisture at that temperature. Consequently the evaporating capacity of atmospheric air is determined by the gradient between the temperature of the air and the body temperature of the animal and, simultaneously, by the quantity of moisture in the atmospheric air.

In the lower portion of Fig. 5 are given the average hourly body temperatures of the animals used in Experiment 1, the average hourly air temperatures and the average relative humidities for the five days. The curve in the central portion of Fig. 5 was derived by calculation from these data. The quantity of water contained in one cubic metre of air saturated with moisture was calculated for each hourly body temperature using the curve in the upper portion of the figure. The quantity of water held in one cubic metre of atmospheric air was calculated for each hour using the experimental data given in the lower portion of the figure. By difference was obtained the quantities of water which were evaporated per cubic metre of inspired air from hour to hour. The heat dissipated in evaporating these quantities of water was calculated and the results are given in the central portion of the figure. It will be noted that in spite of the wide variations in atmospheric temperature the capacity of the air to aid the dissipation of heat by evaporating water within the lungs varied but little owing to the variations in temperature and humidity being inverse. The average evaporating capacity of inspired air was 16.8 Calories per cubic metre, the minimum value being 15.3 and the maximum 17.4 Calories.

## Summary

The diurnal variation in the body temperature of threequarter-bred Holstein-Zebu dairy calves under insular tropical conditions was studied. Two maxima were found to occur, one at about noon and the other at about 6 p.m.

The origin and dissipation of body heat were discussed with special reference to the tropics.

It seemed unlikely that changes in management could materially reduce the degree of hyperthemia observed.

## Acknowledgment

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## CHEMICAL NOTES

*(Compiled by the College Department of Chemistry and Soil Science)*

### Glass Fertilizers

Growing plants in glass flowerpots will feed on the walls of the pots themselves if they are made of a new nutrient glass fertilizer. The glass will supply all the necessary food elements except nitrogen, organic matter and water. This use is suggested by A. E. Badger and R. H. Bray, of the department of ceramics engineering of the University of Illinois, as one of the results of work carried out on the solubility of fused mixtures of rock phosphate, potassium carbonate and silica. Should proper solubilities be obtained with the more complex mixtures, these scientists state, and costs be competitive with present fertilizers, glass fertilizers may offer interesting advantages. The ease with which glass can be manipulated, the scientists say, suggests many commercial adaptations for soilless growth experiments as well as ordinary applications for soil enrichment.—(*Science* **102**, 1945.)

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### Effects of Superphosphate on Orange Trees

The results of tests carried out in most of the citrus growing areas of the Union indicate that applications of superphosphate will cause a decrease in skin thickness and a reduction in the acidity of the juice. In one instance, in the Rustenburg area, mottling of the trees was observed as a result of applying this fertilizer. In this case, apparently an overdose of superphosphate had interfered with the zinc nutrition of the trees, and the trouble was controlled by applications of zinc citrate. Three to seven pounds of superphosphate, well forked, into the soil, is the cure recommended for thick-skinned and acid fruit, especially in the eastern Tranzvaal, provided no mottling is evident. Kraal manure and compost will also help to increase the phosphate content of the tree.—(Abstr. 1197 in *Hort. Abstr.*, **15** from *Fmg. S. Afr.*, 1945, **20**, 351-3).

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The Editor is prepared to consider signed articles for publication in *Tropical Agriculture*. Such articles should normally vary between 1,000 to 6,000 words and may be illustrated if desired.


**EAST MALLING RESEARCH STATION, KENT, ENGLAND**

A Senior Member of Staff required, with good academic qualifications and research experience in the application of Botany or Plant Physiology to horticultural or plantation crops (at home or abroad), to be associated with the Pomology Section and take a share in the Station's general administration. The salary will initially be within the range of £840 to £1,125, according to qualifications and experience ; super-annuation under F.S.S.U.

Applications to be received by the Secretary, not later than 31st October, 1946, giving details of age, health, education, postgraduate career, publications, present salary, date when free, and referees.